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Development Analysis Rural Drinking Water Supply System Network in Tulamben Village, Karangasem District

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ABSTRACT

PAMDES Tirta Gunung Agung utilizes a well with a discharge of 2.53 liters/second as a source of raw water which has served 323 SR (house connections). This research is to analyze efforts to develop SPAMDes to increase services for 130 SRs that do not have water service. A simulation was carried out using Epanet 2.2 software by using Telagawaja SPAM raw water of 1.0 liters/second to increase the shortage of discharge from existing water sources. Simulations that meet the technical criteria are analyzed financially using the parameters Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit Cost Ratio (BCR). Of the 3 (three) development alternatives, only 2 (two) alternatives meet the technical aspects, including: Alternative 2, namely taking raw water discharge from the RD (Distribution Reservoir) Kubu SPAM Telagawaja to Reservoir 1 by gravity via a 2,448 m long pipe with a construction cost of IDR 817. 154,000 have (NPV = Rp. 68,196,373) > 0, (IRR = 6.956%) > MMRA (6%), (BCR = 1.04) > 1, and Alternative 3 is taking raw water discharge from RD Kubu SPAM Telagawaja to the Reservoir 2 through a 1770 m long pipe assisted by a booster pump with construction costs of IDR 693,338,000 having (NPV = IDR 228,880,999) > 0, (IRR = 9.594%) > MMRA (6%) and (BCR = 1.16) > 1. Utilization of raw water from existing wells and additional water discharge from Telagawaja SPAM of 1.0 liters/second can meet water needs in the PAMDES development plan area, as well as planning alternatives 2 and 3 are technically and financially feasible.

Keywords: development, SPAMDes, epanet, water suppy, financial analysis.

INTRODUCTION

Annual population growth and developments in various regional sectors have resulted in increased water demand. Kubu District in Karangasem Regency is one of the areas experiencing limited raw water supply, including Tulamben Village. The Telagawaja SPAM infrastructure development [1] , aims to meet the raw water needs in Karangasem Regency with a capacity of 460 liters per second. Improvements and rehabilitation of the raw water network are still underway in 2019 and 2021. Currently, several PAMDES (Rural Drinking Water Supply) units are serving the water needs of some residents in Tulamben Village, including the Tirta Gunung Agung PAMDES in Beluhu Traditional Village, Tulamben. Utilizing deep groundwater wells (drilled wells) with a flow rate of 2.53 liters per second as a water source, PAMDES can now serve 323 household connections (SR). Challenges arise in service development efforts, as 130 families still do not receive water from PAMDES.

The need for clean water for households (domestic) is expressed in units of Liters/Person/Day (L/O/H), the amount of need depends on the city category based on the number of residents. For the category of semi-urban cities, sub-district/village capitals with a population of 3,000-20,000 people, the need for clean water is 60-90 L/O/H (SNI, 2015). In every clean water supply, it is very difficult to avoid the possibility of water loss from the system. Water loss can be caused by technical and non-technical factors. Technical factors include pipe leaks, water meter damage and others

(equipment factors). While non-technical factors include errors in recording/reading equipment, calculation errors and others. Therefore, in planning a drinking water supply system, a certain volume of water is calculated to avoid the possibility of water loss. This is intended so that the water supply to consumers is not disrupted if water loss occurs. Water loss is assumed to be 20% of the average clean water needs of the population [2], [3]. The total water needs in this PAMDES development plan are 2,547 liters/second and increasing and in the 20th year projection (2043) to 3,069 liters/second.

This research focuses on analyzing efforts to develop PAMDES to improve services for 130 families who have not yet received water. A simulation was conducted using Epanet 2.2 software by utilizing raw water from Telagawaja SPAM at 1.0 liters/second to supplement the lack of discharge from drilled wells which are the existing water source. Simulations that meet the technical criteria are analyzed financially using the parameters of Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit Cost Ratio (BCR) [4]–[6]. This was done to obtain scenarios or alternatives in efforts to develop PAMDES in the Beluhu Tulamben Traditional Village by maximizing the potential of existing raw water so as to increase the capacity and beneficiaries of drinking water services to communities that meet the technical criteria and are financially feasible.

RESEARCH METHODS

Water Requirement Standards

The standard for clean water is 49.9 liters per capita per day. The human body requires 2.5 liters of water per capita. The standard water requirement for humans typically follows the formula of 30 cc per kilogram of body weight per day. Therefore, if a person weighs 60 kg, their daily water requirement is 1,800 cc, or 1.8 liters [7].

The Directorate General of Human Settlements, Department of Public Works, further divides the drinking water requirement standards based on location, as follows:

- Rural areas require 60 liters per capita per day.
- Small cities require 90 liters per capita per day.
- Medium cities require 110 liters per capita per day.
- Large cities with a need of 130 liters per capita per day.
- Metropolitan cities with a need of 150 liters per capita per day.

According to SNI 6728.1:2015 concerning the Preparation of Spatial Natural Resource Balances – Part 1 Water Resources, household (domestic) clean water needs are expressed in liters per person per day (L/O/H). The amount of need depends on the city category based on population, as shown in the following Table 1.

Table 1. Household clean water needs by city category

Number	City Category	Population (people)	Clean water needs (Liters/person/day)
1	Semi-urban (sub-district/village capital	3,000 – 20,000	60 – 90
2	Small town	20,000 - 100,000	90 – 110
3	Medium city	100,000 – 500,000	100 – 125
4	Big city	500,000 - 1,000,000	120 – 150
5	Metropolitan	> 1,000,000	150 - 200

Source: [8]

Planning Criteria

In general, the planning criteria that will be used are based on the Technical Provisions for SPAM pipe networks contained in Attachment III of the Regulation of the Minister of Public Works and Public Housing Number 27/PRT/M/2016 Concerning the Implementation of Drinking Water Supply

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Systems. Other criteria used are also based on the needs and conditions of the clean water service system in the village to be served. The production of drinking water required is for Domestic and Non-domestic service purposes. The following are the criteria for transmission pipes and distribution pipes according to the technical provisions for SPAM pipe networks shown in the following Table 2.

Table 2. Transmission pipe criteria

Number	Description	Notation	Criteria
1	Planning discharge	Q maax	Maximum daily water requirement Q max = F max x Q average
2	Maximum day factor	F max	1.10 – 1.50
3	Channel type		0.3 – 0.6 meter/secons
4	Flow velocity in the pipe		
	a. Minimum speed	V min	
	b. Maximum speed		3.0 – 4.5 meter/secons
	PVC pipe	V max	6.0 meter/secons
	DCIP pipe	V max	
5	Water pressure in pipes		1.0 atm
	a. Minimum pressure	H min	
	b. Maximum pressure	H max	
	- PVC pipe		6 – 8 atm
	- DCIP pipe		10 atm
	- PE pipe 100		12.4 MPa
	- PE pipe 80		9.0 MPa

Source: [9]

Table 3. Criteria for distribution science

Number	Description	Notation	Criteria
1	Planning discharge	Q maax	Maximum daily water requirement Q max = F max x Q average
2	Maximum day factor	F max	1.15 – 3.00
3	Channel type		0.3 – 0.6 meter/secons
4	Flow velocity in the pipe		
	c. Minimum speed	V min	
	d. Maximum speed		3.0 – 4.5 meter/secons
	PVC pipe	V max	6.0 meter/secons
	DCIP pipe	V max	
5	Water pressure in pipes		(0.5-1.0) atm, at the furthest service point
	c. Minimum pressure	H min	
	d. Maximum pressure	H max	
	- PVC pipe		6 – 8 atm
	- DCIP pipe		10 atm
	- PE pipe 100		12.4 MPa
	- PE pipe 80		9.0 MPa

Source: [9]

Loss of Press Height
Major Losses

Major energy loss is caused by friction with the pipe walls. Frictional energy loss is caused by the viscosity of liquids and the imperfections of pipe walls. Several theories and formulas exist for calculating this major head loss, including those from Hazen Williams, Darcy Weisbach, Manning, Chezy, Colebrokk-White, and Swamme-Jain. The Darcy Weisbach equation is most widely used in

general fluid flow, while the Hazen Williams equation can be used for water flow with relatively stable viscosity. The two equations are shown below [10]:.

a. Darcy-Weisbach Equation

The mathematical equation of the Darcy-Weisbach Equation is written as follows:

$$h_f = 8f \frac{L}{D^5}\frac{Q^2}{\pi^2 g} \quad (1)$$

atau

$$h_f = f \frac{L}{D}\frac{V^2}{2g} \quad (2)$$

where:

h_f = Energy or pressure loss (m)
Q = flow rate in the pipe (m3/s)
f = coefficient of friction (Darcy Weisbach)
L = pipe length (m)
D = pipe diameter (m)
g = acceleration due to gravity (m/s2)

Roughness is one of the causes of reduced energy in water or fluid during flow. Roughness is a relative value to the diameter (inside the pipe). The larger the pipe diameter, the smoother it appears, and the lower the coefficient of energy loss due to friction.

b. Hazen Williams Equation

The Hazen Williams equation can be written as follows:

$$Q = C_u \,.\, C_{Hw} \,.\, d^{0,63} . s^{0,54} \quad (3)$$

with Cu = 0,2785, the equation can be written as follows

$$Q = 0{,}2785 \,.\, C_{Hw} \,.\, d^{0,63} . s^{0,54} \quad (4)$$

$$(s = \frac{h_f}{L}) \quad (5)$$

where:

C_{Hw} = Hazen-Williams pipe roughness coefficient
S = slope of the power line
D = pipe diameter (m)
Q = flow rate in the pipe (m3/s)
L = pipe length (m)

So that:

$$h_f = \left(\frac{Q}{0{,}2785 . C_{Hw} . d^{2,63}}\right)^{1,85} \text{ x } L \quad (6)$$

or

$$h_f = \frac{10{,}67 \,.\, Q^{1,852}}{C^{1,852} \,.\, d^{4,8704}} \text{ x } L \quad (7)$$

Minor Losses

Minor energy losses result from bends in the pipe, which cause turbulence. They are also caused by sudden narrowing or enlargement of the pipe cross-section. Energy losses also occur when water must pass through valves. Valves disrupt the flow, reducing or even stopping it altogether. In long pipes, these minor losses are often ignored without significant error (L/D >> 1000), but can be quite significant in short pipes [11]..

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Financial Feasibility Analysis

Financial feasibility analysis is a tool used to determine whether a project plan is financially feasible [12]. The results of this financial analysis will serve as input and form the basis for project implementation decisions. Broadly speaking, financial feasibility analysis can be conducted using several parameters [3], such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit Cost Ratio (BCR).

Method

The stages of the method used in this research are in accordance with the following flow diagram.

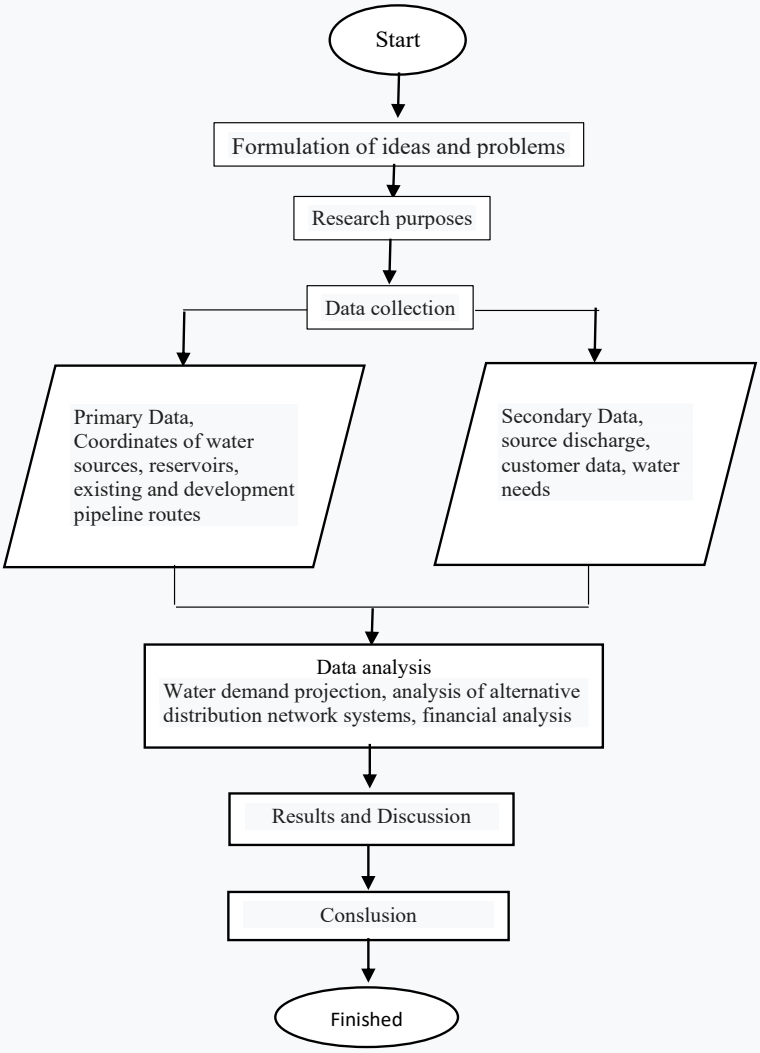


Figure 1. Research flow diagram

Data Source Determination

To obtain a clear picture of the problem solving process, data collection was carried out [13]–[15]. The data used in this study are as follows:

a. Primary Data
   - The existing condition of the SPAMDes (Village Spamdes) in Beluhu Traditional Village, Tulamben Village.

- Coordinates and elevations of water sources, pipes, reservoirs, pumps, and other existing equipment, as determined by a field survey using GPS.
- Network and service development plans, as well as any problems encountered, according to field sources, through interviews.

b. Secondary Data
- Population data for the last five years, from 2018 to 2022. Data obtained from relevant agencies.
- Existing network map including data on transmission, distribution, and pumping pipelines.
- Water consumption data based on the standard daily water requirement per person according to SNI 6728.1:2015 concerning the Preparation of Spatial Natural Resource Accounts – Part 1 Water Resources, for the Semi-urban category (sub-district/village capitals) of 60–90 liters per person per day.
- Water consumption based on customer water sales data at the Village Spam (SPAMDes), recorded according to monthly House Connection (SR) water meter readings obtained from the Village SpamDes Management Group.
- Water source discharge data (deep groundwater wells) using pump test data conducted by the Center for Groundwater Resources and Environmental Geology, Geological Agency, Ministry of Energy and Mineral Resources.

Research Instruments

Research instruments are tools used to collect research data or information. Among the instruments needed for research is the application of the Epanet program. Epanet was designed to be a tool for conducting research to improve our understanding, particularly regarding the behavior and movement of water within a drinking water distribution system [16]–[18]. Using the Epanet program involves several steps:

- Drawing the network with the necessary physical objects or components;
- Setting the object properties within the network system;
- Setting the non-physical components required for the network system, such as time patterns, pump curves, and other controls;
- Selecting a single-period or long-period analysis;
- Running the hydraulic analysis;
- Displaying the analysis results.

Data Processing

The data analysis stage in this study involved evaluating the performance of the existing SPAM and alternative SPAM development plans using the analysis results of the Epanet program. This was followed by calculating the existing conditions and projected water needs to determine whether they met the SPAM planning criteria. Furthermore, alternatives that met the technical criteria were financially feasible using several parameters, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit Cost Ratio (BCR).

RESULT AND DISCUSSION

Existing Conditions of the SPAMDES Service System

The Tirta Gunung Agung Village Water Supply (PAMDES) service system uses a mixed pumping and gravity pumping system, with three pumping stages, pumping water to the distribution reservoir and then distributing it to customers via gravity. In the first stage, water is pumped from the water source (a drilled well) using a submersible pump, which is stored in reservoir 1, located next to the well. In the second stage, water is pumped from reservoir 1 to reservoir 2, located in the courtyard of SDN 4 Tulamben. In the third stage, water is pumped from reservoir 2 to reservoir 3, the distribution reservoir, and then distributed to customers via gravity.

The Tirta Gunung Agung Village Water Supply (PAMDES) piping network consists of transmission and distribution pipes. The transmission pipeline network, consisting of 63 mm diameter GIP and

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PVC pipes, is constructed with a total length of 2,310 m. This pipeline transports water using a pumping system from reservoir 1 (+68 meters above sea level) with a volume of 7.5 m^3 located next to the well/water source to reservoir 2 (+149 meters above sea level) with a volume of 25 m^3 located in the yard of SDN 4 Tulamben, covering a length of 1,150 m with an elevation difference of approximately 81 m. Water is then pumped back from reservoir 2 to reservoir 3 (+237 m), the final reservoir (distribution reservoir), covering a length of 1,160 m with an elevation difference of approximately 88 m.

The distribution pipeline network, constructed by the 2019 Pamsimas III Program, consists of 90 mm diameter PVC pipes with a length of 2,370 m, which transport water from reservoir 3 (the distribution reservoir) to customers in the Beluhu Kauh Hamlet area by gravity. The reservoir was built using the 2019 Tulamben Village Budget (APBDes), with a storage capacity of 130 m^3.

The existing scheme of the Tirta Gunung Agung Village Water Supply System (PAMDES) can be seen in the Figure 2.

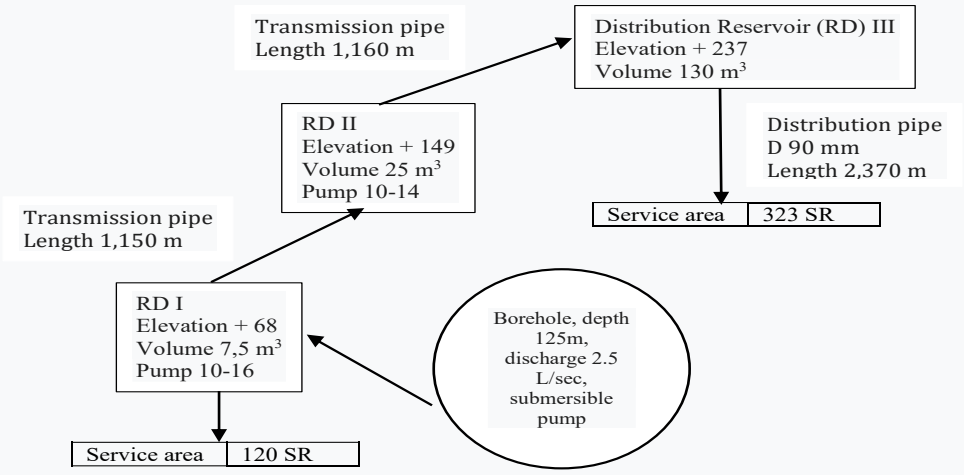


Figure 2. Existing Scheme of PAMDES Tirta Gunung Agung

Population Growth and Water Demand Projections

Population projections are used as a baseline in calculating projected clean water needs. Once the projection method is determined, the projected population (clean water users) and clean water needs in the service area for 2023 to 2043 are calculated. This is done using baseline data on the number of House Connections (SR) for water users (PAMDES customers and water user groups) in 2023.

Network Development Planning Analysis

The network development plan aims to increase the number of PAMDES Tirta Gunung Agung services for the Beluhu Traditional Village community by 130 SR. In year 0 (2023), the total water demand for existing and planned users, after adding a 20% water loss factor, is 2,547 liters/second. This total water demand continues to increase, reaching 3,069 liters/second in the projected year 20 (2043).

The total water requirement in the service development plan has exceeded the water source (drilled well) discharge of 2.53 lt/sec, so in this study the Tirta Gunung Agung PAMDES service development plan will utilize raw water sourced from Telaga Waja SPAM of 1.00 lt/sec taken from the Kubu Distribution Reservoir (RD) of Telaga Waja SPAM. The Kubu Distribution Reservoir (RD) is located in Dukuh Village, Kubu District at an altitude of 144 meters above sea level which has a distance of approximately 1.8 km from the existing drilled well with a reservoir capacity of 600 m^3. The existing pipe scheme and the Tirta Gunung Agung PAMDES development plan can be seen in the following Figure 3.

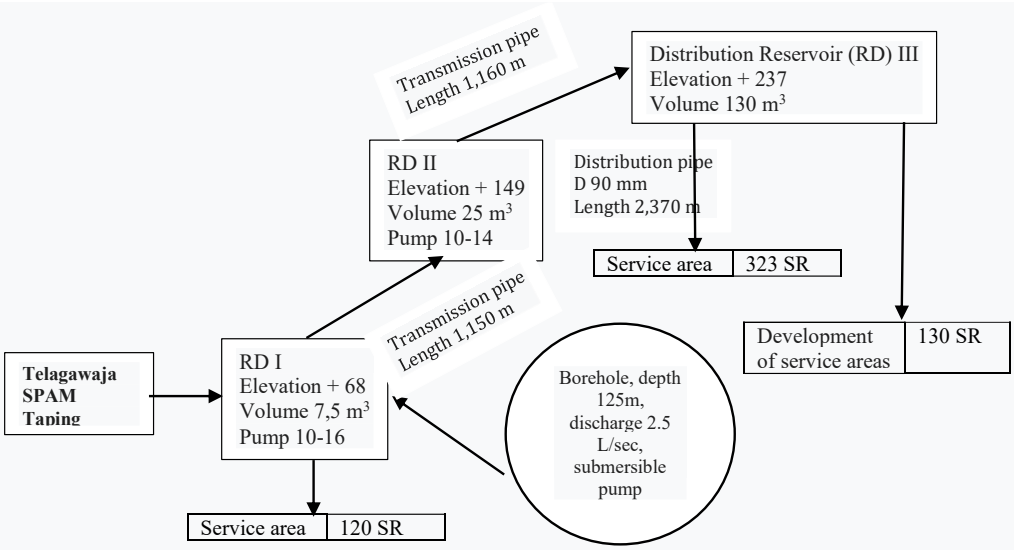


Figure 3. SPAMDes Development Plan Scheme

Alternative Development Planning Analysis 2

In alternative planning 2, water discharge intake from the Kubu SPAM Telaga Waja Distribution Reservoir (RD) is planned to use a 2 inch or 60 mm diameter GIP pipe to Reservoir 1 with a total length of 2,448 m. The first section is 1,555 m long from RD Kubu to Jalan Desa in Dusun Beluhu Kangin and 888 m long in the second section flows by gravity to Reservoir 1 which is located next to the existing drilled well. The distribution pipe development network with a total length of 1,738 m is planned to use a PVC pipe with a diameter of 60 mm in the JDt5 segment (the end of the existing pipe junction) to JDP1 with a length of 612 m. Meanwhile, in the JDP1 to JDP4 segment (the last junction in the development plan) with a length of 1,126 m, it is planned to use PVC with a diameter of 48 mm and 32 mm in the last section as well as the addition of PRV in this segment to reduce pressure.

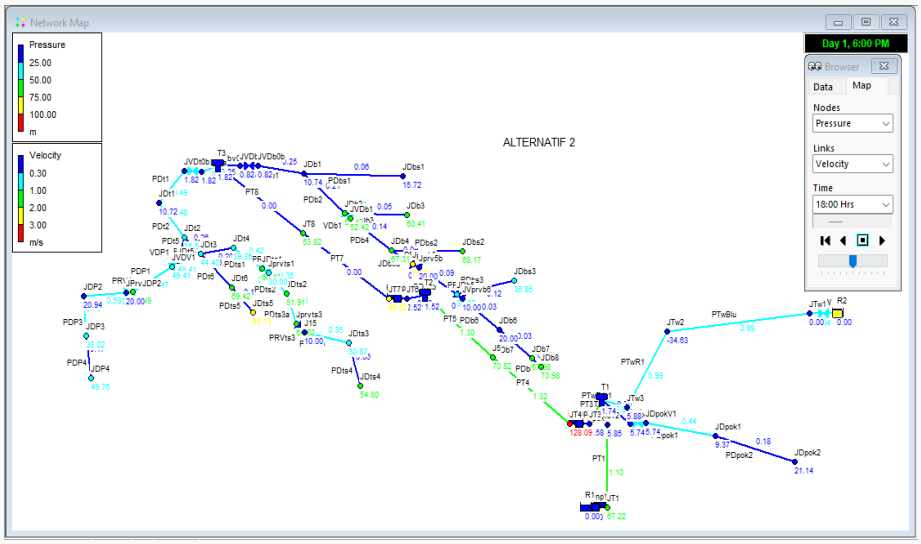


Figure 4. Results of running Epanet alternative 2 at the maximum water usage hour of 18.00

Simulation results for alternative 2 indicate that the transmission pipeline network from the Dukuh River to Reservoir 1 has a velocity of 1.0 m/s and is capable of flowing 2.26 liters of water per second. This result meets the minimum velocity criteria of 0.30–0.60 m/s and a maximum velocity

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of 4.5 m/s. The maximum pipe pressure in this segment is 76 m, a maximum pressure value that is acceptable for GIP pipes.

For the distribution pipeline in the service network development plan, in the JDt5 segment (the end of the existing pipe junction) to JDP4 (the final junction in the planned service area), after installing a PRV (pressure reducing valve), the maximum pipe pressure is 56.41 m. This value meets the maximum pressure criterion of 8 atm (80 mKa) for PVC pipes. Similarly, the flow velocity in this PAMDES network development plan is also met. The distribution pipeline in segments PDP1 to PDP4 has a flow rate of 0.58 m/s, meeting the minimum flow rate standard of 0.30–0.60 m/s. Therefore, the PAMDES network development in alternative 2 meets the technical criteria and can be used, and its investment feasibility can be calculated.

Analysis of Alternative Development Planning 3

In alternative 3, additional discharge is taken from the Kubu Distribution Reservoir (RD) of the Telaga Waja Water Supply System (SPAM). The Kubu Distribution Reservoir (RD) is located in Dukuh Village, Kubu District, at an elevation of 144 meters above sea level and has a capacity of 600 m^3. Water intake from the Kubu Distribution Reservoir (RD) of the Telaga Waja Water Supply System (SPAM) is planned using a 2-inch (60 mm) diameter (OD) GIP pipe with a total length of 1,770 m to Reservoir 2. In this alternative, the water flow is directed directly to Reservoir 2 to reduce the capacity or pumping hours of pump 2, which pumps water from Reservoir 1 to Reservoir 2, thus reducing operational costs (electricity costs).

Because the elevation of Reservoir 2 is higher than that of the Kubu RD, this alternative requires the addition of a booster pump to the network. The first pipe section is 1,555 m long from RD Kubu to Jalan Desa in Dusun Beluhu Kangin, then a booster pump is installed before entering the second pipe section with a length of 210 m to flow water to Reservoir 2. The distribution pipe development network is still the same as in alternative planning 2. The running results of alternative 3 can be seen in the following figure:

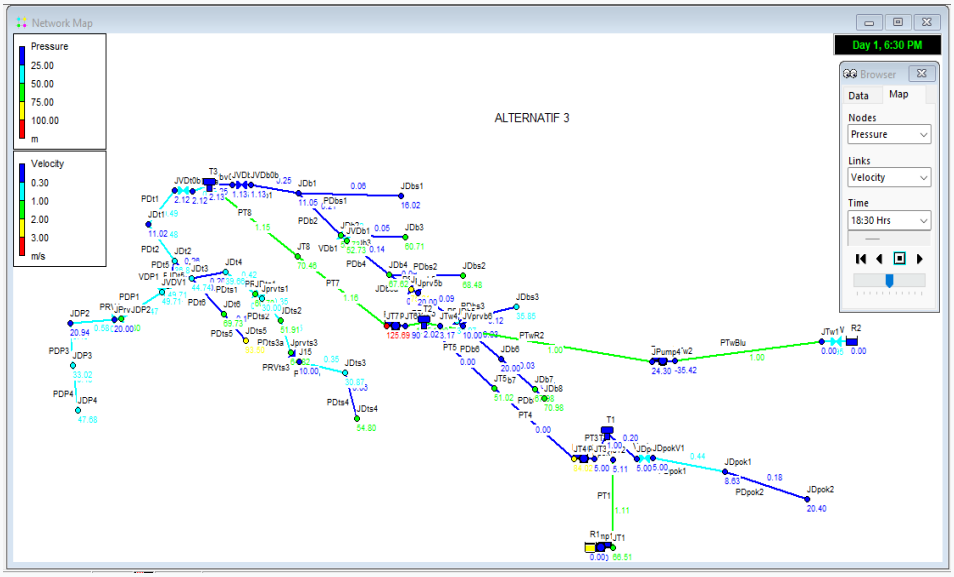


Figure 5. Results of running Epanet alternative 3 at the maximum water usage hour of 18.00

Simulation results for alternative 3 indicate that the transmission pipeline network from the Dukuh Village Road segment to Reservoir 2, after passing through the booster pump (Pump 4), has a velocity of 1.01 m/s and is capable of flowing water at a discharge of 2.28 liters/s. These results meet the minimum pipe velocity criteria of 0.30–0.60 m/s and a maximum velocity of 4.5 m/s. The maximum pipe pressure in this segment is 18.32 m, a maximum pressure value acceptable for GIP pipes.

The distribution pipeline in the service network development plan is the same as in alternative 2 and meets the standard distribution pipeline planning criteria. Therefore, the development of the PAMDES network in alternative 3 meets the technical criteria and can be used and its investment feasibility calculated.

Financial Feasibility Analysis

Financial feasibility analysis is used as a reference for development implementers and serves as a benchmark for the feasibility of infrastructure development in a region, particularly the construction of public facilities. In this study, the NPV, IRR, and BCR parameters were analyzed. Previously, the cost calculations, including construction costs or the Cost Budget Plan (RAB), were calculated. At this stage, the costs for each selected alternative, namely Alternatives 2 and 3, which met the technical criteria, were outlined. Alternative 1 was not considered for discussion in the financial feasibility analysis because it no longer met the technical criteria.

A summary of the technical and financial analysis results for the PAMDES development can be seen in the following table, showing the velocity values along the pipe and the pressure values at each node.

Table 4. Summary of Analysis Results on Development Network

FINANCIAL		**Alternative 2**	**Alternative 3**
	Biaya Konstruksi (Rp)	817.154.000	693.338.000
	NPV (Rp)	68.196.373	228.880.999
	IRR (%)	6,956%	9,594%
	BCR	1,04	1,16
Technical		**Alternative 2**	**Alternative 3**
Transmission Network			
Segment	**Indicator**		
RD Dukuh Telaga Waja - Junction Jln. Beluhu	Velocity (m/s)	0,99	1,00
	Pressure (m)	10,00	24,40
Junction Jln. Beluhu - Reservoir 1	Velocity (m/s)	0,99	-
	Pressure (m)	76,00	-
Junction Jln. Beluhu - Reservoir 2	Velocity (m/s)	-	1,00
	Pressure (m)	-	24,40
Distribution Network		**Alternative 2**	**Alternative 3**
Segment	**Indicator**		
JDt5 -JDP1 Ujung pipa Eksisting - Junction Dist Pengembangan 1	Velocity (m/s)	0,47	0,47
	Pressure (m)	61,72	61,79
JDP1 -JDP2 Junction Dist Pengembangan 1 - Junction Dist Pengembangan 2	Velocity (m/s)	0,58	0,58
	Pressure (m)	26,51	26,51
JDP2 -JDP3 Junction Dist Pengembangan 2 - Junction Dist Pengembangan 3	Velocity (m/s)	0,40	0,40
	Pressure (m)	39,43	39,43
JDP2 -JDP3 Junction Dist Pengembangan 3 - Junction Dist Pengembangan 4	Velocity (m/s)	0,43	0,43
	Pressure (m)	56,24	56,24

Source: 2026 Analysis Results

CONCLUSION

Based on the discussion and analysis conducted, the following conclusions can be drawn: 1) The performance of the existing PAMDES network generally meets the criteria and is capable of meeting the needs of the community or PAMDES customers who have not been served by the PDAM. 2) The borehole well flow rate of 2,530 liters/second as a water source is insufficient for the network

expansion plan, which aims to increase the number of services by 130 SRs in the first year to 2,547 liters/second, with an estimated projected total water demand of 3,069 liters/second over the next 20 years. 3) Utilizing raw water from the Telagawaja SPAM (Water Supply System) at 1.0 liter/second through the Kubu Distribution Reservoir to meet the water shortage. 4) Based on the analysis of three alternative development plans, two alternatives were identified that meet the technical and financial feasibility criteria, as follows: a) Alternative 2. In Alternative 2, the transmission pipeline network transports water from the Kubu SPAM Telaga Waja Distribution Reservoir (RD) by gravity to Reservoir 1, via a 60 mm diameter GIP pipe capable of flowing water at a maximum flow rate of 2.26 liters/second. Meanwhile, the distribution pipeline network in the planned service development area uses PVC pipes with diameters of 60, 48, and 32 mm. The construction cost for Alternative 2 is Rp817,154,000, with an NPV of Rp68,196,373, an IRR of 6.956%, and a BCR of 1.04. Alternative 3. In Alternative 3, the transmission pipeline network transports water from the Kubu SPAM Telaga Waja Distribution Reservoir (RD) to Reservoir 2 with the addition of a 25.08 m head booster pump, via a 60 mm diameter GIP pipe capable of flowing water at a maximum flow rate of 2.28 liters/second. Meanwhile, the distribution pipe network in the planned service development area remains the same as the previous alternative, using PVC pipes with diameters of 60, 48, and 32 mm. The construction cost for Alternative 3 is Rp693,338,000 with an NPV value of Rp228,880,999, an IRR of 9.594%, and a BCR of 1.16. Alternative 2 and Alternative 3 have differences in their transmission networks, with Alternative 3 having the lowest construction costs with technical and financial analysis results meeting the criteria.

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